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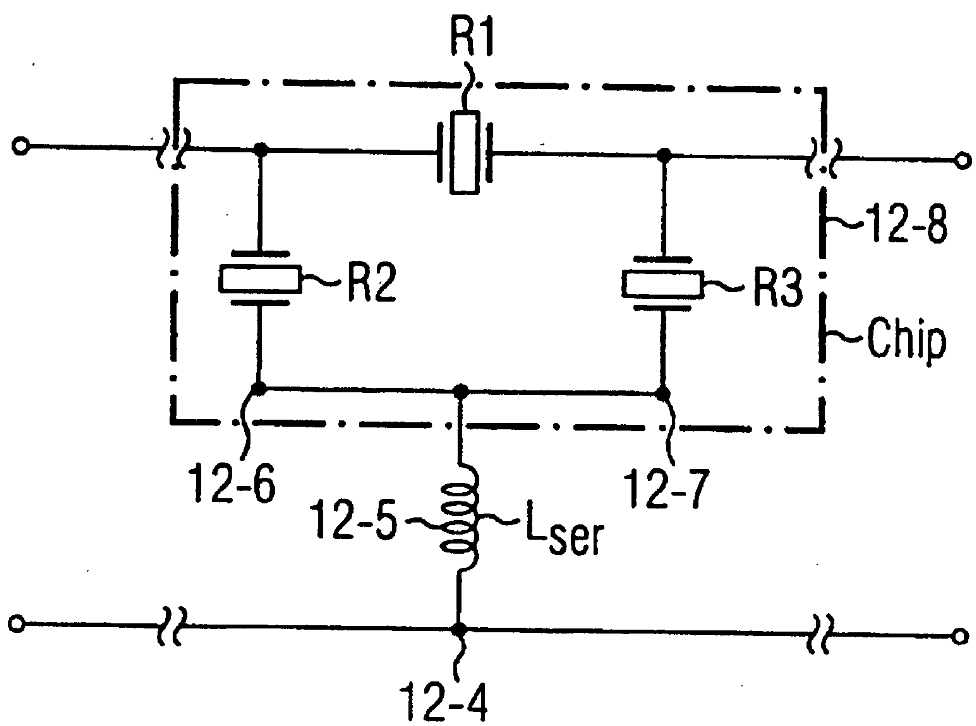
(54) Titre : FILTRE A ONDES DE SURFACE DE TYPE FILTRE A REACTANCE A SUPPRESSION AMELIOREE DE LA BANDE DE FREQUENCES NON TRANSMISES ET PROCEDE D'OPTIMISATION DE LA SUPPRESSION DE LA BANDE DE FREQUENCES NON TRANSMISES

(54) Title: SURFACE ACOUSTIC WAVE (SAW) FILTER OF THE REACTANCE FILTER TYPE EXHIBITING IMPROVED STOP BAND SUPPRESSION AND METHOD FOR OPTIMIZING THE STOP BAND SUPPRESSION



(57) Abrégé/Abstract:
The invention relates to a surface acoustic wave (SAW) filter of the reactance filter type comprising at least two SAW resonators (R2, R3) in two parallel branches and comprising a SAW resonator (R1) in a serial branch. According to the invention, an electric connection, said connection being produced on the substrate, of the ground sides (12-6, 12-7) of both SAW resonators (R2, R3) in the parallel branches is provided before the connection (12-5) to the housing in order to be able to shift the pole location associated with the parallel branch to a lower frequency.

Abstract

SAW Filter of the Reactance Filter Type with Improved Stop Band Suppression and Method for Optimizing the Stop Band Suppression

In a SAW filter of the reactance type having at least two SAW resonators (R2, R3) in two parallel branches and a SAW resonator (R1) in a serial branch, it is proposed that an electrical connection fashioned on the substrate of the ground sides (12-6, 12-7) of the two SAW resonators (R2, R3) in the parallel branches be provided before the bonding (12-5) to the housing in order to achieve a shift of the pole point belonging to the parallel branch to a lower frequency.

Figure 12

SAW FILTER OF THE REACTANCE FILTER TYPE WITH IMPROVED STOP BAND SUPPRESSION AND METHOD FOR OPTIMIZING THE STOP BAND SUPPRESSION

The present invention is directed to a surface-active wave filter (SAW) and, specifically, to a SAW filter of the reactance filter type with improved stop band suppression as well as to a method for the optimization of the stop band suppression.

Reactance filters are known from classical filter technology. When SAW resonators are employed for the individual resonators instead of discrete elements (inductances and capacitors), then this is called a SAW filter according to the reactance filter type.

Given SAW filters of the reactance filter type, SAW resonators are employed as impedance elements. Figure 1 shows the schematic structure of a known resonator. It comprises metallic structures on the surface of a piezo-electric substrate and has a terminal pair 1-1 and 1-2 to which an interdigital transducer 1-4 is connected for the transformation of electrical energy into acoustic energy. A reflector1-3 and 1-5 is respectively arranged at both sides of the interdigital transducer 1-4 along the acoustic axis in order to prevent the acoustic energy from escaping.

At the left, Figure 2 shows the equivalent circuit diagram for a SAW resonator R and shows the symbol employed for the resonator at the right. A series resonant circuit composed of dynamic inductance L_1, dynamic capacitor C_1 and dynamic resistor R_1 (when taking losses into consideration) is located in the first branch of the parallel circuit, and the static capacitor C_0 of the interdigital transducer is located in the second branch. The series resonant circuit reflects the behavior of the resonator in the resonance case, i.e. in the range of the resonant frequency f_r. The static capacitor reflects the behavior in the frequency ranges $f<<f_r$ and $f>>f_r$. The dynamic capacitor C_1 is proportional to the static capacitor C_0 of the interdigital transducer:

$$C_1 \sim C_0 \tag{1.1}$$

A resonator has a resonant frequency f_r and an anti-resonant frequency f_a. The following applies to the resonant frequency f_r:

$$f_r = \frac{1}{2\pi} \sqrt{L_1 * C_1} \qquad (1.2)$$

The following applies for the anti-resonant frequency f_a of a resonator:

$$f_a = f_r * \sqrt{1 + C_1/C_0} \qquad (1.3)$$

The basic unit of a SAW reactance filter is what is referred to as a basic element as shown in Figure 3. It is composed of a first resonator R_1 with resonant frequency f_{rp} and appertaining anti-resonant frequency f_{ap} in the parallel branch and of a second resonator R_2 with resonant frequency f_{rs} and appertaining anti-resonant frequency f_{as} in the serial branch. The frequency curve of the admittance Y_p of the resonator R_1 in the parallel branch and the frequency curve of the impedance Z_s of the resonator R_2 in the serial branch are shown in Figure 4. For producing a band-pass filter with the middle frequency f_0, the resonant frequencies of the two resonators have the following relationship:

$$f_{ap} \approx f_{rs} \approx f_0 \qquad (1.4)$$

Each basic element is to be fundamentally viewed as two-port with the terminals 3-1 or, respectively, 3-2 of port 1 and the terminals 3-3 or, respectively, 3-4 of port 2 (see Figure 3). At the same time, the terminals 3-1 is the input and the terminal 3-3 is the output of the series resonator. The input of the parallel resonator is connected to the terminal 3-1. The terminals 3-2 and 3-4 represent the reference ground given an asymmetrical operation. The output 3-5 of the parallel resonator that faces toward the reference ground is referred to below as output side or, respectively, ground side of the parallel resonator. The inductance L_{ser} that lies between the output side of the parallel resonator and the reference ground reflects the connection to the housing ground in the real structure.

The selection level of the SAW filter according to the reactance filter type is defined, first, by the relationship C_{0p}/C_{0s} of static capacitor C_{0p} in the parallel branch and static capacitor C_{0s} in the series branch and is defined, second by the plurality of basic elements connected following one another (cascaded).

The basic elements in the case of a cascading are usually circuited adapted, i.e. respectively mirrored. Figure 5 and Figure 6 show two examples of a reactance filter wherein respectively two basic elements are cascaded. The output impedance 5-1 (Z_{out}) or, respectively, 6-1 (Z_{in}) of the first basic element is equal to the input impedance 5-2 or, respectively, 6-2 of the second basic element, as a result whereof the losses due to mismatching are minimal. Many structures are possible or known for reactance filters with respect to the plurality and arrangement of the basic elements.

Resonators of the same type (series resonator or parallel resonator) lying immediately behind one another can also be respectively combined to form one, whereby the capacitative overall effect remains the same. The interconnection of a filter according to Figure 7 corresponds in effect to that of a filter according to Figure 8.

Figures 9 and 10 show the typical, actual structure of a SAW filter on a piezoelectric substrate 9-1 in a ceramic housing 9-0 and the typical connecting technique with bond wires 9-8 through 9-12 or, respectively, 10-9.

At the output side 9-15 through 9-17, the parallel resonators R1, R3 and R5 are connected to the housing ground pads 9-4, 9-5 and 9-7 via bond wires 9-9, 9-10 and 9-12.

As a result of the typical structuring technique (see Figure 9 and Figure 10), series inductances between, for example, the output side 9-17 of the parallel resonator R5 on the substrate (chip) 9-1 and the ground 10-5 adjacent at the outer housing pin 9-4 are obtained given the connection of the parallel branches to ground. These essentially include the inductive part of the stripline on the chip, the inductance of the bond connection 9-9 and that of the housing lead-through 10-3.

These series inductances influence the behavior of the filter both in the passband as well as in the stop band. $f \ll f_0$ applies for the pass band. The resonant frequency and, thus, the bandwidth of a resonator can, as known, be modified by an external wiring belonging to the resonator. An inductance serially with the resonator increases the effective dynamic inductance, as a result whereof the resonant frequency f_r drops. Since the anti-resonant frequency f_a is shifted to only a very slight extent, the

bandwidth $\Delta f = f_a - f_r$ of a resonator is increased with the serial inductance. The bandwidth of the SAW filter is also increased in the case of a parallel resonator.

$f \ll f_0$ and $f \gg f_0$ applies for the stop band. Here, the equivalent circuit diagram of a resonator is reduced to its static capacitance C_0 since the series resonant circuit is extremely high-impedance beyond f_0 and corresponds to a no-load. An inductance L_{ser} serially with the resonator yields a series resonant circuit shown in Figure 11 having a resonant frequency

$$f_{pol} = 1/2\pi \sqrt{L_{ser} * C_0} \qquad (1.5)$$

In the case of an inductance serially with a parallel resonator, this means that the energy of the filter can flow off directly to ground given the frequency f_{pol}; what is referred to as a pole point thus forms in the filter curve, i.e. an increased suppression in the stop band. A plurality of pole points in the stop band corresponds to the plurality of parallel branches with series inductance. Pole points f_{pol1} and f_{pol2} that can be distinguished from one another in terms of frequency derive only given different products $\Pi_1 = L_{ser1} * C_{01}$ and $\Pi_2 = L_{ser2} * C_{02}$. When the products are identical, then the pole points lie at the same frequency; a double pole point $f_{pol} = f_{pol1} = f_{pol2}$ is obtained with a higher suppression than given a simple pole point.

Figure 11a shows the attenuation behavior of a resonator in the parallel branch to which an inductance L_{ser} is serially connected at the output side of the parallel resonator. As in Figure 11b, the series resonant circuit of the resonator whose resonant frequency $f_{rp} = f_0$ was removed in order to illustrate the pole point. What typically applies for the frequency of the pole point f_{pol} is $f_{pol} > f_0$, whereby f_0 is equal to the resonant frequency of the filter. A high attenuation is then obtained for the pole point.

SAW filters of the reactance filter type are mainly employed as RF filters in the mobile radio telephone field since they exhibit extremely low losses in the pass band. As RF filter in the mobile radio telephone field, the SAW filter of the reactance filter type must, over and above this, suppress, first, the duplex band (i.e., the reception band given a transmission filter and, conversely, the transmission band given a reception filter) and, second, must suppress the signal at the local oscillator

frequency (LO) and/or at the image frequency in order to prevent unwanted mixed products in the telephone.

The local oscillator lies above or below the middle frequencies f_0 of the filter. The distance from the middle frequency f_0 corresponds to the intermediate frequency (ZF) employed for the signal editing. The image frequency has the spacing 2*ZF from the middle frequency f_0. Since momentary ZF frequencies in the range 100-400 MHz are employed, the SAW filter - dependent on the application - must comprise good attenuation properties of, typically, more than 30 dB in the range f_0 plus/minus 100-800 MHz. In the most frequent instances, the local oscillator lies above the middle frequency f_0.

There are various possibilities for achieving an adequate attenuation in the range of the LO frequency and/or image frequency. Possibly A is comprised therein that the general selection level be made correspondingly high (the minimum attenuation below the pass band given approximately $f_0/2$ is valid as criterion for this). The great disadvantage is, however, that the losses in the pass band also increase with increasing selection level. This is unacceptable for the signal processing in the telephone in most cases. The second possibility B derives from the aforementioned fact that an inductance present given the traditional structuring technique generates a pole point serially with a parallel resonator that lies exactly at the LO or image frequency. Given the great spectrum of ZF frequencies employed, a possibility must be established in this case in order to vary the generated pole point over a range of approximately 700 MHz.

Since the static capacitance C_{0p} in the parallel branch is the determining factor for the filter performance (passband, matching and selection level), it can only be varied to an extremely slight degree with given filter demands such that the position of pole points in the stop band also simultaneously changes. Likewise, the degree of freedom for the size of the inductance serially between output side of the parallel resonator and ground is limited. Due to the necessity for miniaturization as well as for cost reasons, the chips that are employed are becoming smaller and smaller, this resulting therein that the inductive part of the stripline on the chip can be varied to only a limited extent. The length and the inductance of the bond connection

correlating therewith can likewise hardly be varied any more with any housing in the course of the progressing miniaturization. Moreover, the inductance that derives from the housing lead-through is fixed for a given housing.

The possibility B is thus also not established anymore to an adequate extent for SAW filters according to the reactance filter type in housings that have been miniaturized further, namely it is no longer established to an adequate degree in order to assure the LO and/or image suppression by means of suitably placed pole points over a great frequency range from f_0 plus 100-800 MHz. Particularly given the future connection technology of "flip-chip-technique" wherein bump connections are employed instead of the bond wires, it is impossible to generate pole points at relatively low frequencies, i.e. in the range of 100 MHz above the middle frequency f_0, since the inductances present given this structuring technique serially to the output side of a parallel resonator are too small (see Equation 1.5), and the static capacitances of the parallel branches can likewise not be selected great enough because of the required self-matching to 50Ω.

It is therefore an object of the present invention to specify a way of how a filter can be designed such that an improved stop band suppression can be obtained for specific LO frequencies and image frequencies over a possible range from 100 through 800 MHz next to the middle frequency. In particular, a way should be specified for shifting pole points of a reactance filter into a desired region close to the middle frequency f_0 without greatly influencing the remaining filter behavior.

This object is inventively achieved with a filter according to claim 1. Advantageous developments in a method for shifting pole points may be derived from further claims.

As a result of a connection of the ground-side output sides of the parallel branches respectively comprising a resonator on the chip, a coupling of the parallel branches is inventively produced, as a result whereof the frequency position of the appertaining pole point (also referred to as "coupled pole point" below) can be modified to a great extent. As a result thereof, it is possible to produce a SAW filter that comprises pole points at lower frequencies than could be achieved by the previous, serial interconnection of the parallel branches with existing, structure-

conditioned inductances according to Equation (1.5). It is also possible to shift one or more pole points in a given filter over a broader frequency range than was hitherto possible in a given filter. With the invention, thus, a pole point can be generated exactly at the frequency at which a high selection is required, for example at an arbitrary LO or image frequency.

Such demands for the suppression of signals at the local oscillator frequency (LO suppression) and/or at the image frequency (image suppression) can thus still be satisfied in extremely small housings having very low structure-conditioned inductances. One or more pole points can be shifted to a desired frequency given an established bond inductance, conduct inductance or housing lead-through inductance without this requiring an increase in the serial inductance. Additionally, of course, the serial inductance can also be increased.

Moreover, the plurality of ground connections that are offered can be set independently of the plurality of parallel branches employed, this leading to a lower space requirement. It is precisely in view of new connecting technologies (bump connections instead of bond connections) and new housing technologies that the embodiments according to the invention represent the sole possibility for achieving the aforementioned selection demands in miniaturized housings.

The principle for shifting the pole points according to the present invention shall be explained in greater detail below on the basis of exemplary embodiments and the appertaining figures. The following, concrete embodiments are examples of the employment in a SAW filter of the reactance filter type.

Thereby shown are:

Fig. 1 a one-port SAW resonator;

Fig. 2 the equivalent circuit diagram and symbol for a SAW resonator;

Fig. 3 a basic element of a SAW filter of the reactance filter type;

Fig. 4 interaction of parallel and series resonators;

Fig. 5 cascade of two basic elements;

Fig. 6 cascade of two basic elements;

Fig. 7 diagram of a reactance filter;

Fig. 8 diagram of a reactance filter with the reduced structure s-p-s-p;

Fig. 9 plan view onto a SAW filter in the housing without cover;

Fig. 10 cross-section through a SAW filter in the housing;

Fig. 11a pole point;

Fig. 11b equivalent circuit diagram for the attenuation behavior of a parallel branch;

Fig. 12 equivalent circuit diagram of a filter;

Fig. 13 equivalent circuit diagram for the attenuation behavior of a SAW filter;

Fig. 14 diagram that shows the relationship between ΔL_{ser} and pole point;

Fig. 15 dependency of the frequency position of the pole point on the static capacitance;

Fig. 16 filter having three basic elements;

Fig. 17 the equivalent circuit diagram thereof in the stop band;

Fig. 18 the attenuation behavior thereof;

Fig. 19 filter with four basic elements;

Fig. 20 the equivalent circuit diagram thereof in the stop band;

Fig. 21 the attenuation behavior thereof;

Fig. 22 filter with four basic elements;

Fig. 23 the equivalent circuit diagram thereof in the stop band;

Fig. 24 the attenuation behavior thereof;

Fig. 25 filter with four basic elements;

Fig. 26 the equivalent circuit diagram thereof in the stop band;

Fig. 27 the filter characteristic thereof;

Fig. 28 filter with four basic elements

Fig. 29 the equivalent circuit diagram thereof in the stop band;

Fig. 30 filter structure with bump connection;

Fig. 31 filter structure with bond connection.

Fig. 12 shows a simple filter structure of the invention symbolically as a equivalent circuit diagram, this being potentially part of a larger filter structure with further basic elements. Given (at least) two of the parallel branches with the parallel resonators R2 and R3, the output sides 12-6 and 12-7 are already inventively electrically connected to one another on the chip (substrate) 12-8. Only thereafter

does a connection to the housing ground pad 12-4 comprising, for example a bond connection 12-5, ensue.

Fig. 13 shows the equivalent circuit diagram for the frequency range $f \ll f_0$ and $f \gg f_0$ wherein only the static capacitance C_0 takes effect for each resonator. The selection behavior of a SAW filter according to the reactance filter type can be largely described with this reduced equivalent circuit diagram. The inductance L_{ser} corresponds to the inductance between the connection of the parallel resonators on the chip and the housing ground pin (equals terminal for ground at the housing) outside.

A coupling of the two parallel branches already electrically connected on the chip occurs. This leads to a frequency position change of the pole points in the stop band. The frequency position of the coupled pole point can be identified on the basis of the equivalent circuit diagram from Figure 13, which shows a two port Z. The two port Z then comprises a pole point when the impedance to ground becomes zero.

$$Z_{21} = 0$$

Z_{21} is thereby a systematically referenced matrix element from the impedance matrix. For determining Z_{21}, the two port Z can be divided into a series circuit of the two-ports Z' and Z". The two-port Z' comprises the Π-circuit composed of the three capacitors C_{op1}, C_{op2} and C_{os}. The two-port Z" comprises only the inductance L_{ser}. The following thus derives:

$$Z'_{21} = \frac{1}{j\omega\left(C_{0p2}C_{0p1} + \frac{C_{0p1}C_{0p2}}{C_{0s}}\right)} \qquad (2.1)$$

$$Z''_{21} = j\omega L_{ser} \qquad (2.2)$$

Whereby j= represents the imaginary number and $\omega = 2\pi f$ applies.

With

$$Z_{21} = Z'_{21} + Z''_{21} \qquad (2.3)$$

it follows that

$$Z_{21} = \frac{1-\omega^2 L_{ser}\left(C_{0p2}+C_{0p1}+\dfrac{C_{0p1}C_{0p2}}{C_{0s}}\right)}{j\omega\left(C_{0p2}+C_{0p1}+\dfrac{C_{0p1}C_{0p2}}{C_{0s}}\right)} \tag{2.4}$$

When the numerator of the expression of (2.4) becomes zero,

$$1-\omega^2 L_{ser}\left(C_{0p2}+C_{0p1}+\frac{C_{0p1}C_{0p2}}{C_{0s}}\right) = 0 \tag{2.5}$$

Z_{21} becomes zero. The following is obtained therefrom for the frequency position of the coupled pole point:

$$f_{pol\ (coupled)} = \frac{1}{2\pi\sqrt{L_{ser}\left(C_{0p2}+C_{0p1}+\dfrac{C_{0p1}C_{0p2}}{C_{0s}}\right)}} \tag{2.6}$$

It can be clearly seen compared to the pole points previously obtained without coupling of the parallel branches on the chip according to Equation (1.5).

$$f_{pol} = 1/2\pi\sqrt{L_{ser} * C_{opl}} \tag{2.7}$$

$$f_{pol2}\ 1/2\pi\sqrt{L_{ser} * C_{op2}} \tag{2.8}$$

That the additional capacitance parts $\dfrac{C_{opl}C_{op2}}{C_{os}}$ and C_{op2} or, respectively, C_{opl} shift the coupled pole point to a far lower frequency given the same inductance L_{ser}.

Numerical example: for a known SAW filter of the reactance filter type, the frequency f_{pol} of a pole point is calculated as:

$$f_{pol}1 = \frac{1}{2\pi\sqrt{L_{ser} \cdot C_{op1}}} = \frac{1}{2\pi\sqrt{1nH \cdot 4pF}} = 2.52\ GHz$$

Typical values of 1nH and 4pF were thereby assumed for the serial inductance L_{ser} and for the static capacitance C_{op}.

According to Equation 2.6 and given the same assumed values for L_{ser} and C_{0p} and likewise given 4pF for C_{0s},

$$f_{pol}2 = \frac{1}{2\pi\sqrt{1nH * (rpF + 4pF + (4pF)^2\ /\ 4pF)}} = 1.45\ GHz$$

derives when two parallel branches are coupled.

When a filter comprises a plurality of parallel branches, then a plurality of parallel branches can also be connected to one another at the ground side, these also continuing to be referred to as "coupled parallel branches". The plurality and combination of the connected parallel branches plays a critical part for the frequency position of the coupled pole points and is to be taken into consideration in the selection of the filter structure for a desired frequency position of the pole points.

Fig. 14 indicates the dependency of the position of a coupled pole point on the size of the inductance L_{ser}. The two curves 14-1 and 14-2 indicate the filter behavior for the same filter, whereby only L_{ser} has been differently selected. A different frequency position of the pole points derives dependent on L_{ser}, whereby the inductance $L_{ser}1$ belonging to $f_{pol}1$ is smaller than $L_{ser}2$. The shift of the pole points toward lower frequencies is all the greater the higher the inductance L_{ser} is.

To a lesser extent, the frequency position of the pole point can be set by a variation of the product of static capacitances of the coupled parallel branches

$$\Pi_p C = C_{0p1} * C_{0p2} \qquad (2.9)$$

So that the filter behavior in the passband and the general selection level is not modified, such a variation of the product of static capacitances in the parallel branch can be implemented only upon retention of their sum:

$$\Sigma C_p = C_{0p1} + C_{0p2} = \text{constant} \qquad (2.10)$$

The following method can be applied: the static capacitance C_{op1} of the first couple parallel resonator is increased by the same amount C_{const}

$$C_{0p1}(\text{new}) = C_{op1} + C_{const} \tag{2.11}$$

by which the static capacitance C_{0p2} of the second couple parallel resonator is lowered:

$$C_{op2}(\text{new}) = C_{0p2} - C_{const} \quad \text{with } C_{const} < C_{0p2}, \tag{2.12}$$

so that the product $\Sigma\, C_p$ in fact changes but the sum of the static capacitances remains identical.

$$\Sigma\, C_p = C_{0p1}(\text{new}) + C_{0p2}(\text{new}) = C_{0p1} + C_{0p2} = \text{constant} \tag{2.13}$$

and no modifications of the passband or of the general selection level need be accepted.

When a greater frequency offset of the couple pole point is necessary, the participating static capacitances C_{0p1}, C_{0p2} or C_{0s} can be varied. When more parallel resonators than the two parallel resonators to be coupled are present, then the sum $C_{0p1} + C_{0p2}$ can be raised (or lowered), and the static capacitance of a non-coupled parallel resonator can be lowered (or raised) for balancing such that the total sum of all static capacitances remains the same in the parallel branches. The general selection level is retained as a result thereof.

Fig. 15 shows how, given a constant inductance L_{ser}, the frequency of the couple pole point is increased as a result of a reduction of the sum of the static capacitances $C_{0p1}+ C_{0p2}$ of the coupled parallel branches, being increased by the factor 1.2. For balancing, the static capacitance of a further parallel branch was correspondingly increased.

Another possibility for shifting the couple pole point is comprised in intentionally splitting a parallel resonator P into two individual resonators P' and P" parallel to one another, whereby the sum of the capacitances of the split, individual resonators is equal to the original capacitances C_{0p}:

$$C_{0p} = C'_{0p} + C''_{0p}.$$

When one of these parallel resonators P′ is coupled with a further parallel resonator but not with the parallel resonator P′′, then the frequency position of the

coupled pole point can be set on the base is of the division ratio $\frac{C'_{0p}}{C''_{0p}}$ of the static capacitance of the split parallel resonators P' and P", since C'_{0p} influences the frequency position of the coupled pole point.

A single series resonator or a plurality of series resonators can be arranged between coupled parallel branches. Since the size of the static capacitance C_{0s} that lies between the coupled parallel resonators influences the frequency position of the coupled pole point according to Equation 2.6, the frequency position of the coupled pole point can likewise be shifted with the following method.

When further series resonators S_n in addition to the series resonator or resonators S lying between the coupled parallel branches are present, then the static capacitance C_{0s} thereof can be raised (or lowered) and, for balancing, the static capacitance of the series resonators S_n that do not lie between the coupled parallel resonators can be lowered (or raised) such that the total sum of all static capacitances in the series branches remains the same. As a result thereof, the general selection level is retained and the frequency position of the coupled pole point is modified.

As already explained, the range for the variation of the static capacitances C_p in the parallel branch and of the serial inductances L_{ser} (between the connection of the parallel branch on the chip and the outside terminal at the housing) is limited. The same is therefore also true for the frequency range in which the pole points can be displaced. In contrast to the measures known from the prior art, however, the range of variation achieved according to the invention enables the manufacture of SAW filters - even given extremely miniaturized housings - with a LO suppression and image suppression that is required for the employment as RF filter in the mobile radio telephone field.

Concrete embodiments of inventive filters are now recited below.

Embodiment 1 (also see Fig. 16 through Fig. 18):

A structure having three basic elements is employed. A first basic element is connected such to the input port 16-1 that both the parallel branch as well as the series branch comprise a connection to the input port. The second basic element is connected according to the matching demand $Z_{out} = Z_{in}$. The third basic element follows in the same way. Differing from the case at the input port, only one series branch is thus directly connected to the output port. A sequence *p-s - s-p - p-s* for the resonators derives from the input to the output, whereby *p* stands for parallel resonator and *s* stands for series resonator. Fundamentally, input port and output port can be interchanged without modifying the filter properties, whereby the sequence *s-p-p-s-s-p* derives.

As known, identical resonators can also be combined upon retention of their capacitative effect. The following structures with minimum number of resonators thus derive:

p-s-p-s or, respectively, *s-p-s-p*

however, mixed forms having partial combination of the resonators area also possible:

p-s-p-p-s or, respectively, *s-p-p-s-p*

p-s-s-p-s or, respectively, *s-p-s-s-p*

For the sake of simplicity, the embodiments below are only explained on the basis of minimum of resonators and without additional indication of the interchangeability of input port and output port and are shown this way in the Figures. Nonetheless, the invention also comprises modifications according to the example that has just been explained above.

Fig. 16 symbolically shows the structure of embodiment 1. The two parallel branches are already electrically connected to one another on the chip and a connection to the housing only ensues subsequently. The equivalent circuit diagram for the selection behavior in the range $f \ll f_0$ and $f \gg f_0$ is shown in Fig. 17. The inductance L_{ser} corresponds to an inductance between the connection of the parallel resonators on the chip and the housing ground pin outside.

The filter has a filter characteristic as identified by curve 18-1 in Fig. 18. The comparison to filter curve 18-2 (corresponding to the filter shown in Fig. 8) wherein the parallel branches on the chip are not connected to one another, clearly

shows how the frequency position of the pole points in the stop band with a typical inductance $L_{ser} = 1.0$ nH is shifted by the connection of the parallel branches on the chip. The selection is increased by more than 10 dB in the frequency range between the vertical lines (typical frequency range for LO suppression and image suppression given low intermediate frequency).

Embodiment 2 (also see Fig. 19 - Fig. 21):

Fig. 19 symbolically shows the structure of a second inventive embodiment wherein a structure having four basic elements is employed. A first basic element is connected such to the input port 19-1 that both the parallel branch as well as the series branch comprise a connection to the input port. The second basic element is connected according to the matching requirement $Z_{out} = Z_{in}$. Basic element 3 and 4 follow in the same way. Just as at the input port, both a parallel branch as well as a series branch are thus directly connected to the output port 19-3. A sequence for the resonators from the input to the output derives as follows:

p-s-p-s-p

whereby *p* stands for parallel resonator and *s* stands for series resonator. Resonators of the same type are already combined.

Two of the three parallel branches are already electrically connected to one another on the chip and a connection to the housing only ensues subsequently via the inductance L_{ser2}. The remaining parallel branch is connected to the housing independently thereof via the inductance L_{ser1}. The equivalent circuit diagram for the selection behavior in the range $f \ll f_0$ and $f \gg f_0$ is shown in Fig. 20. The inductance L_{ser2} corresponds to an inductance between the connection 19-4 of the parallel resonators on the chip (shown with the broken line in the Fig.) and the housing ground pin outside.

In Fig. 21, the curve 21-1 shows the filter characteristic of the filter from Fig. 19. The comparison with the filter curve 21-2 wherein the parallel branches are not connected on the chip clearly shows how the frequency position of the pole points in the stop band given a typical inductance $L_{ser2} = 1.0$nH is shifted toward lower frequencies due to the connection of two of the three parallel branches on the chip

here. The selection is increased by approximately 10 dB in the frequency range between the vertical lines (typical frequency range for LO suppression and image suppression at low intermediate frequency).

Embodiment 3 (also see Fig. 22 - Fig. 24):

Fig. 22 symbolically shows the structure of the inventive embodiment 3. A structure having three basic elements is employed. A first basic element is connected such to the input port 22-1 that only the series branch comprises a connection to the input port. The second basic element is connected according to the matching requirement $Z_{out} = Z_{in}$. Basic element 3 and 4 follow in the same way. Just as at the input port, only one series branch is thus directly connected to the output port 22-3. A sequence for the resonators from the input to the output derives as follows:

s-p-s-p-s

whereby *p* stands for parallel resonator *s* stands for series resonator. Resonators of the same type are already combined. The two parallel branches are already electrically connected to one another on the chip and a connection to the housing only ensues subsequently. The equivalent circuit diagram for the selection behavior in the range $f \ll f_0$ and $f \gg f_0$ is shown in Fig. 23. The inductance L_{ser} corresponds to an inductance between the connection of the parallel resonators on the chip and the housing ground pin outside. The filter from 22 has a filter characteristic as identified by curve 24-1 in Fig. 24. The comparison to the filter curve 24-2, whereby the parallel branches are not connected on the chip, it clearly shows how the frequency position of the pole points in the stop band given a typical inductance $L_{ser} = 1.0$ nH is shifted due to the connection of the two parallel branches on the chip. The selection is increased by more than 8 dB in the frequency range between the vertical lines (typical frequency range for LO suppression and image suppression at high intermediate frequency).

Embodiment 4 (also see Fig. 25 - Fig. 27):

Fig. 25 symbolically shows the structure of the inventive embodiment 4. A structure and four basic elements is employed. A first basic element is connected such to the input port 25-1 that only the series branch having the resonator R_{S1}

comprises a connection to the input port. The second basic element is connected mirrored because of the matching demand $Z_{out} = Z_{in}$. Basic element 3 and 4 follow in the same way. Just as at the input port, only one series branch is thus directly connected to the output port 25-3. A sequence for the resonators from input to output derives as follows:

s-p-s-p-s

Resonators of the same type are already combined; in contrast to the embodiment 3, however, one parallel branch has been intentionally divided again. The division ensues such that each parallel resonator R_{p2}, R_{p3} forms its own two-port with its own electrical inputs and outputs. The combined parallel branch having the resonator R_{p1} together with one of the non-combined, two parallel branches (R_{p2}) are already electrically connected to one another on the chip at .25-2, and a connection to the housing only ensues subsequently via L_{ser1}. The remaining parallel branch (R_{p3}) is connected to the housing independently thereof. The equivalent circuit diagram for the selection behavior in the range $f<<f_0$ and $f>>f_0$ is shown in Figure 26. The inductance L_{ser1} corresponds to an inductance between the connection of the parallel resonators R_{p1} and R_{p2} on the chip and the housing ground pin outside; the inductance L_{ser2} corresponds to an inductance between the parallel resonator R_{p3} on the chip and the housing ground pin outside.

The filter from Fig. 25 has a filter characteristic that is characterized by curve 27-1 in Fig. 27. The comparison to the filter curve 27-2, wherein the output sides of the parallel branches are not connected on the chip, clearly shows how the frequency position of the pole points in the stop band given a typical inductance L_{sesr1} = 1.0 nH is shifted due to the connection of two of the three parallel branches on the chip. The selection is increased generally by more than 5 dB in the frequency range between the vertical lines (typical frequency range for LO suppression and image suppression given high intermediate frequency). The selection gain is far more than 10 dB when either a high LO suppression or image suppression is demanded.

Embodiment 5 (also see Fig. 28-Fig. 30):

Fig. 28 symbolically shows the structure of the inventive embodiment 5. A structure having four basic elements is employed. A first basic element is connected such to the input port 28-1 that only the series branch comprises a connection to the input port. The second basic element is connected according to the matching demand $Z_{out} = Z_{in}$. Basic element 3 and 4 following in the same way. Just as at the input port, only one series branch is thus directly connected to the output port 28-3. A sequence for the resonators from input to output derives as follows:

s-p-s-p-p-s

Resonators of the same type are already combined similar to embodiment 4; however, one parallel branch is intentionally divided again. The division, however, does not ensue into two parallel resonators that are independent of one another but in the form of a three-port. The input 4 both parallel resonators is composed of a shared terminal strip 28-4 at which the interdigital fingers to be excited lie. The terminal strip of the output is divided into two bus bars 28-5 and 28-6, whereby each bus bar corresponds to the output of one of the two parallel resonators.

The parallel branch with the resonator R_{p1} together with one of the non-combined parallel resonators R_{p2} are already electrically connected to one another on the chip at the ground output 28-2. A connection to the housing only ensues subsequently. The remaining parallel branch with the parallel resonator R_{p3} is connected to the housing independently thereof. The equivalent circuit diagram for the selection behavior in the range $f \ll f_0$ and $f \gg f_0$ is shown in Fig. 29. It is basically comparable to the equivalent circuit diagram in Fig. 26. The inductance L_{ser1} corresponds to an inductance between the connection of the parallel resonators R_{p1} and R_{p2} on the chip and the housing ground pin outside; the inductance L_{ser2} corresponds to a further inductance between the non-coupled resonator R_{p3} and the housing ground pin outside.

The filter from Fig. 28 has a filter characteristic that does not differ from the filter from Fig. 26 and is therefore also characterized by curve 27-1 in Fig. 27. In contrast to the embodiment 4, a different form of the division of a parallel resonator is shown here, this differing essentially in the layout but not in the effect on the selection behavior.

Fig. 31 shows portions of an inventive filter structure as a schematic plan view onto a substrate. The resonators R are shown as interdigital transducers. The two coupled resonators R_{p1} and R_{p2} in the parallel branch are electrically connected to one another on the substrate and comprise a shared ground connection 31-1 that is connected to a ground terminal pad 31-3 by a bond wire 31-2, which represents one part of the inductance L_{ser}. The connection on the substrate is realized here with a stripline but can also comprise a bond wire. Even though only two coupled resonators are shown here, the invention also covers filters having more than two coupled resonators.

Embodiment 6:

The description of a sixth embodiment of the present invention now follows, portions thereof being shown in Fig. 30. A SAW filter of the reactance filter type having at least two parallel branches is employed. In at least two of all existing parallel branches R2 and R3, the output sides (30-3 and 30-4) of the parallel resonators are already electrically connected to one another electrically on the chip. The connection 30-5 to the housing only ensues subsequently. The remaining parallel branches are connected to the housing independently thereof. The connection of the chip (30-1) to the housing is not implemented as previously as a bond connection but is produced with a bump connection (30-5).

The equivalent circuit diagram for the selection behavior in the range $f \ll f_0$ and $f \gg f_0$ has not changed compared to the general exemplary embodiment and can be seen in Fig. 13. The inductance L_{ser} corresponds to an inductance between the connection of the parallel resonators on the chip and the housing ground pin outside. Given a structuring in bump technology, the value for the inductance L_{ser} is greatly reduced compared to an embodiment with bond wire since the bond connection itself has its nearly no inductance in contrast to a bond connection. Only the inductive part of the stripline on the chip and the housing lead-through inductance up to the external housing ground pin remaining.

Fundamentally, all of the exemplary embodiments shown up to now, even though it is with more than four basic elements having at least two parallel branches at the output side already electrically connected on the chip, can be realized in conjunction with the bump technology. The filter characteristics are also fundamentally comparable; however, the value that can be achieved for the serial inductance L_{ser} is lower. In order to achieve the required selections, for example in the range of the LO suppression and/or image suppression, it is thus all the more necessary to employ the inventive method for targeted variation of the stop band. The invention also offers the advantage of reducing the plurality of necessary ground bumps and, thus, the chip area for ground terminals. As a result thereof, the overall SAW filter can be miniaturized even further.

Patent Claims

1. Method for shifting a pole point in an SAW filter

comprising at least one basic element (R1, R2) fashioned on a piezoelectric substrate (12-8), said basic element comprising a first SAW resonator (R2) in a parallel branch and a SAW resonator (R1) in a serial branch,

comprising at least a further SAW parallel resonator (R3) in a further parallel branch,

whereby the ground sides (12-6, 12-7) of the first SAW resonator (R1) and of the further SAW parallel resonator (R3) in the further parallel branch are electrically connected on the substrate and thereby coupled,

whereby the coupling is arranged between the substrate and the bonding (12-5) to the housing,

characterized in that

the static capacitance C0p of at least one of the coupled parallel resonators is raised or lowered and, for compensation, the static capacitance of one or more non-coupled parallel resonators is lowered or raised such that the overall sum ΣC_{0p} of the static capacitances of all parallel resonators remains identical.

2. Method according claim 1, whereby the static capacitance C_{0s} of at least ones series resonator between two resonators in the parallel branch connected at the ground side is raised or lowered compared to a starting value and, for compensation, the static capacitance of one or more series resonator not lying in the serial branch between the coupled parallel resonators is lowered or raised such that the overall sum ΣC_{0s} of the static capacitances of all series resonators remains identical.

3. Method according to one of the claims 1 or 2,

whereby a parallel resonator is divided into parallel resonators P' and P'',

whereby one of the parallel resonators P' and P'' is coupled to a further parallel resonator, and

whereby the static capacitance C_{0p} of one of the two coupled parallel resonators is varied by means of the division ratio of the static capacitances of the divided parallel resonators P' and P'' and, thus, the frequency position of the coupled pole point is set.

4. Method according to one of the preceding claims, whereby the product ΠC_{0p} of the static capacitances $C_{0p}1$ and $C_{0p}2$ of the parallel resonators electrically connected at the output side is varied in that the static capacitance $C_{0p}1$ of the first parallel resonator is raised by the same amount Cconst by which the static capacitance $C_{0p}2$ of the second parallel resonator is lowered, so that the sum of the static capacitances remains identical.

5. Method according to one of the preceding claims, whereby the link to the housing is undertaken with a bond connection.

6. Method according to one of the claims 1 through 4, whereby the link to the housing is undertaken with a bump connection.

7. Method according to one of the preceding claims, whereby the coupling of the two parallel resonators is undertaken with a bond connection.

Fetherstonhaugh & Co.
Ottawa, Canada
Patent Agents

FIG 1

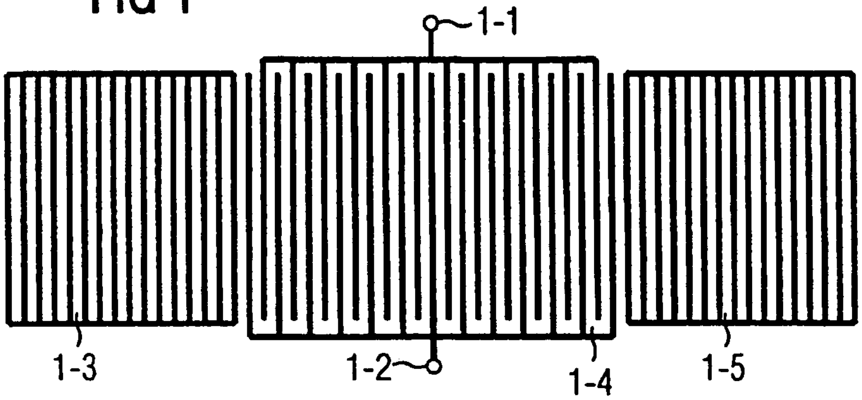


FIG 2

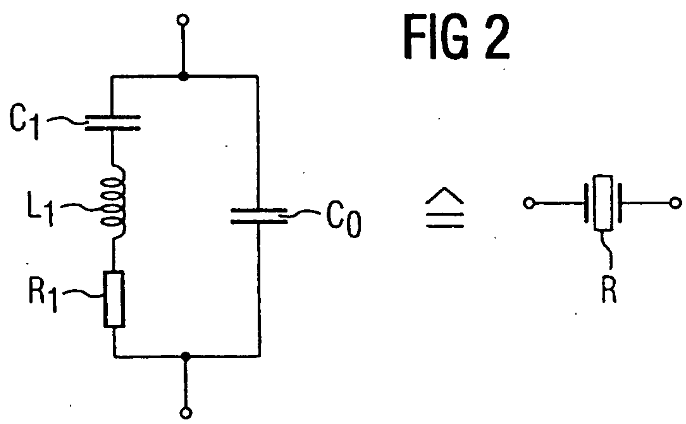


FIG 3

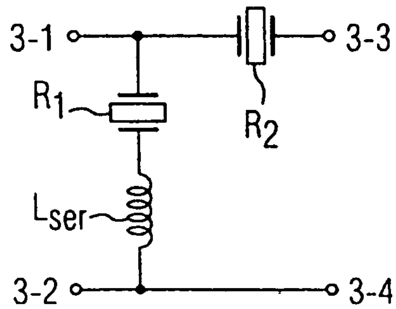


FIG 4

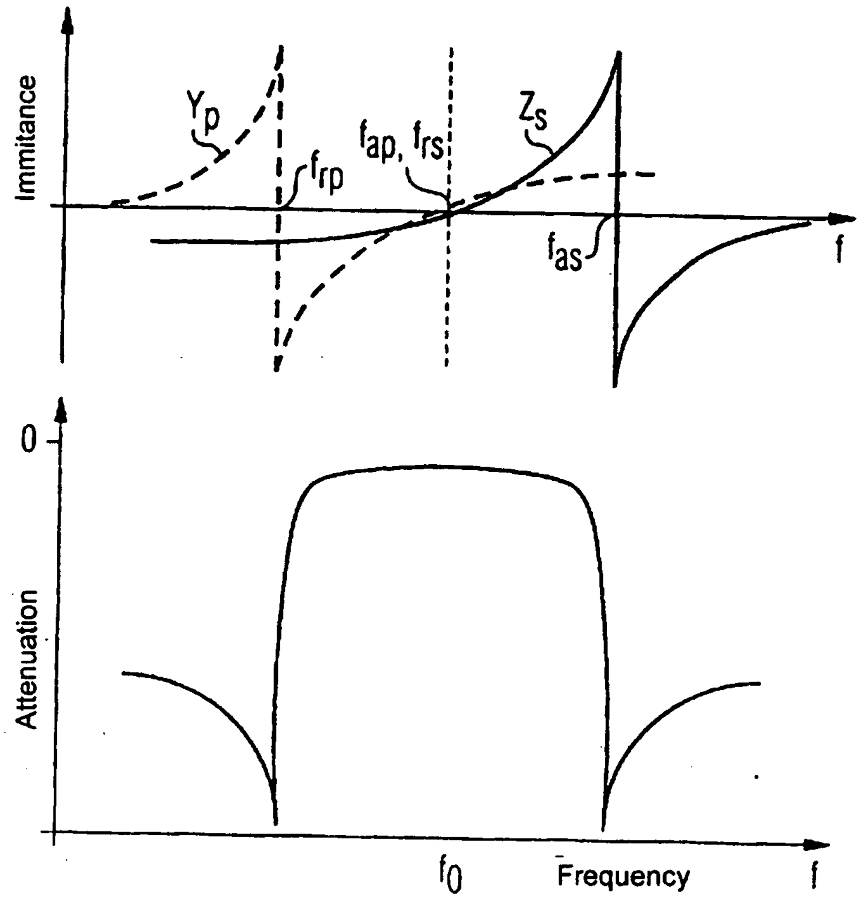

Immitance
Yp
frp
fap, frs
Zs
fas
f
0
Attenuation
f0
Frequency
f

FIG 5

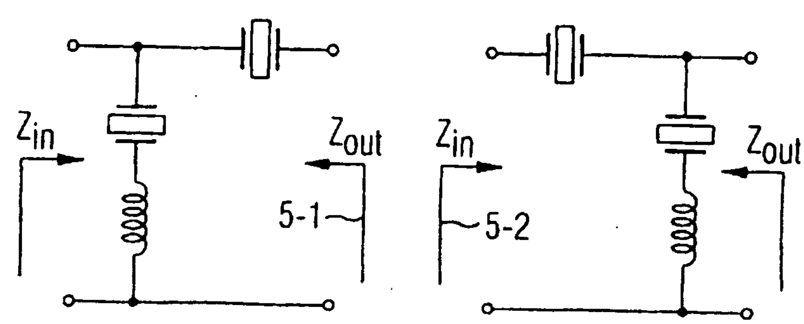

Zin
Zout
5-1
Zin
5-2
Zout

FIG 6

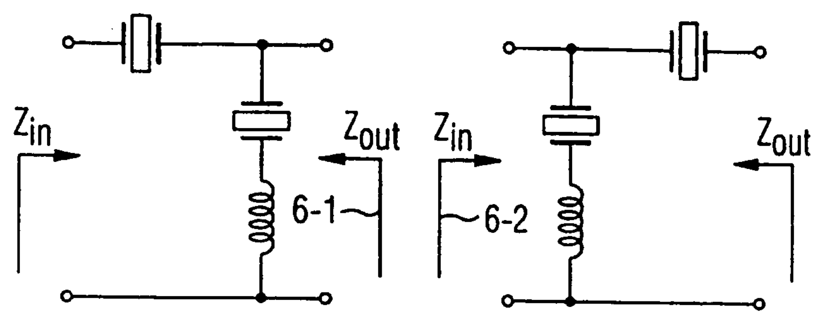


FIG 7

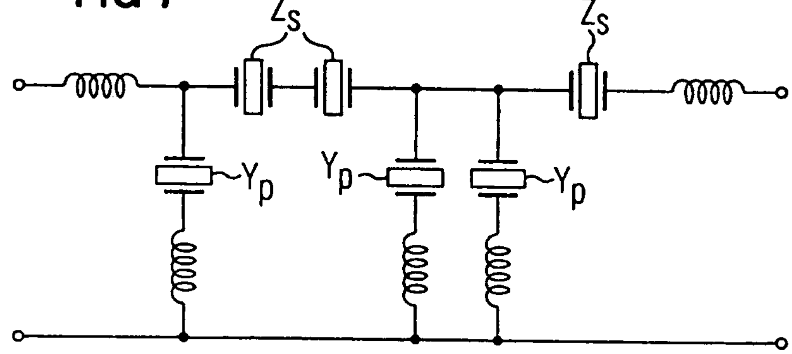


FIG 8

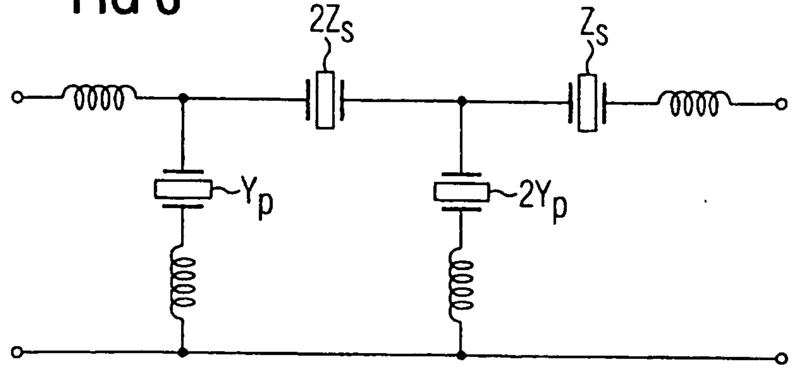


FIG 9

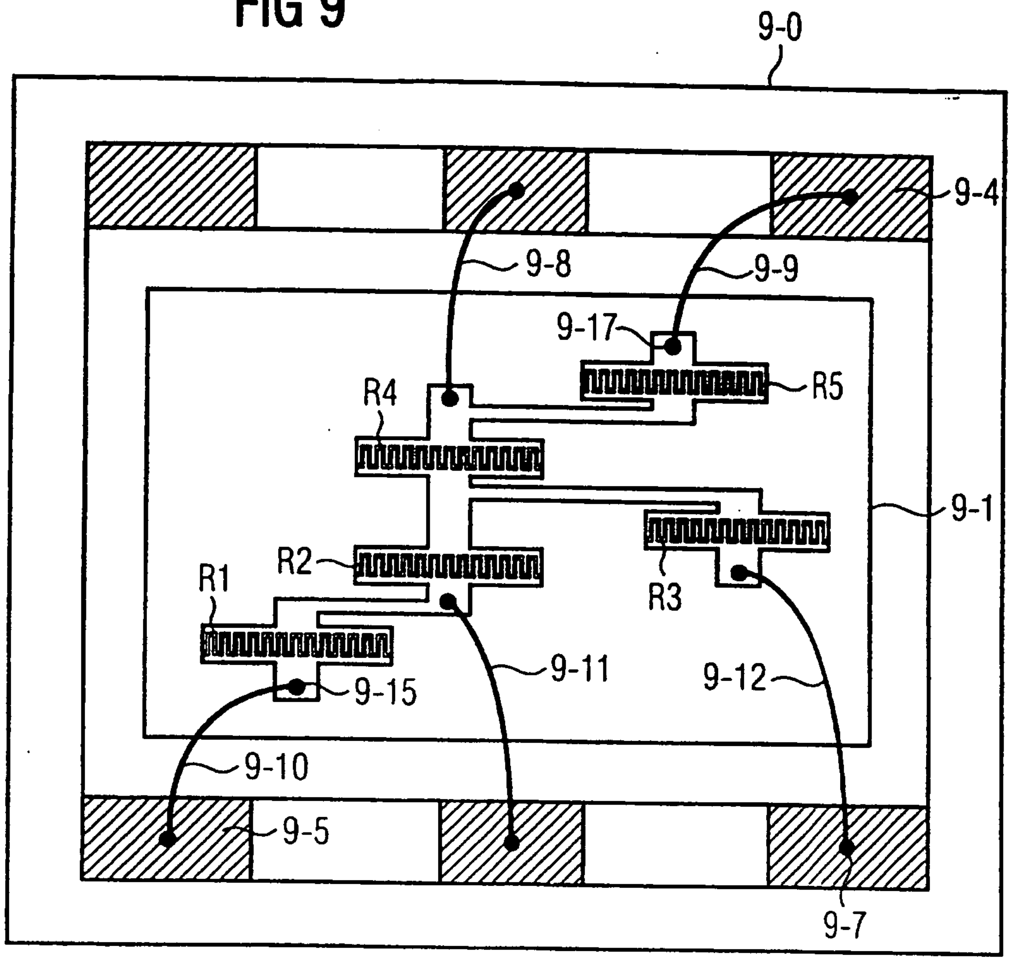

9-0
9-4
9-8
9-9
9-17
R5
R4
9-1
R2
R1
R3
9-11
9-12
9-15
9-10
9-5
9-7

FIG 10

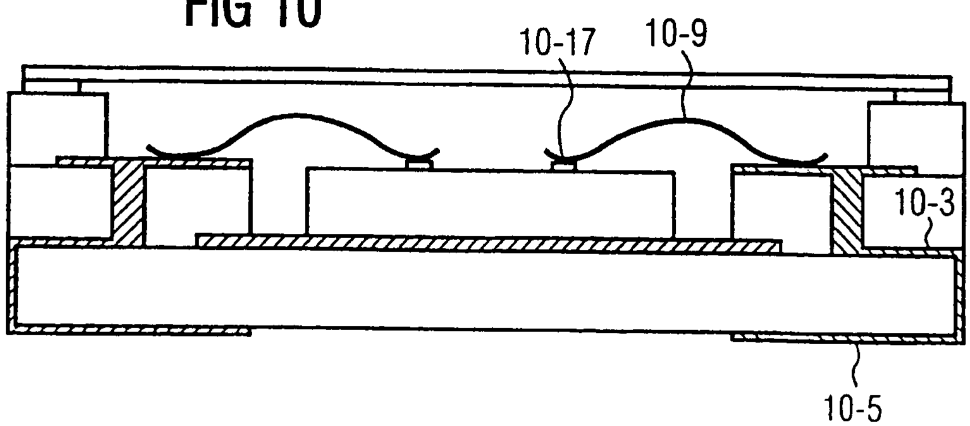

10-17
10-9
10-3
10-5

FIG 11A

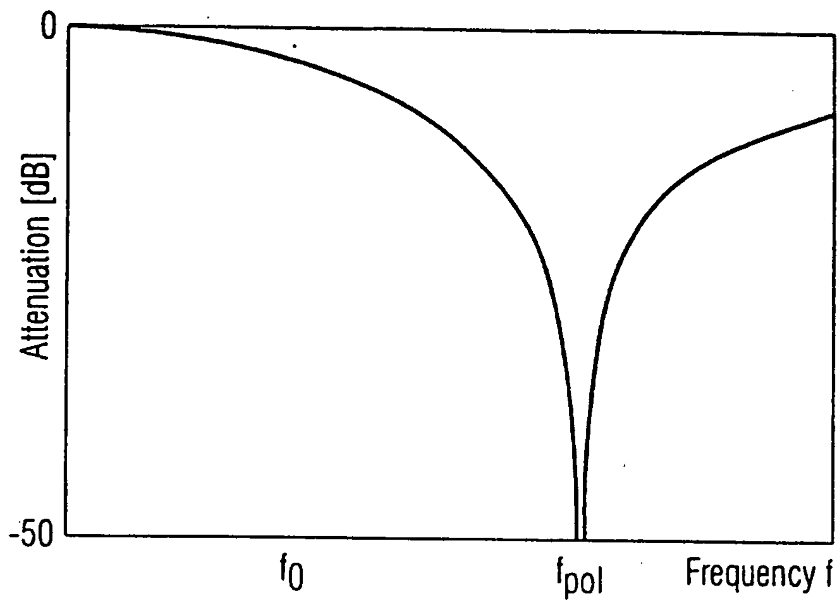


FIG 11B

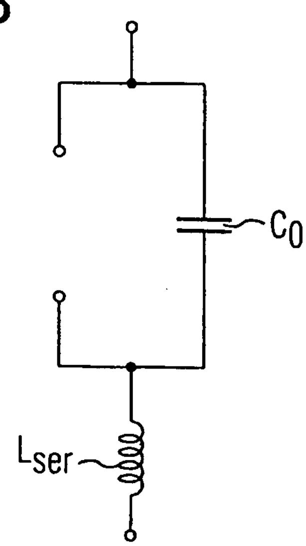


FIG 12

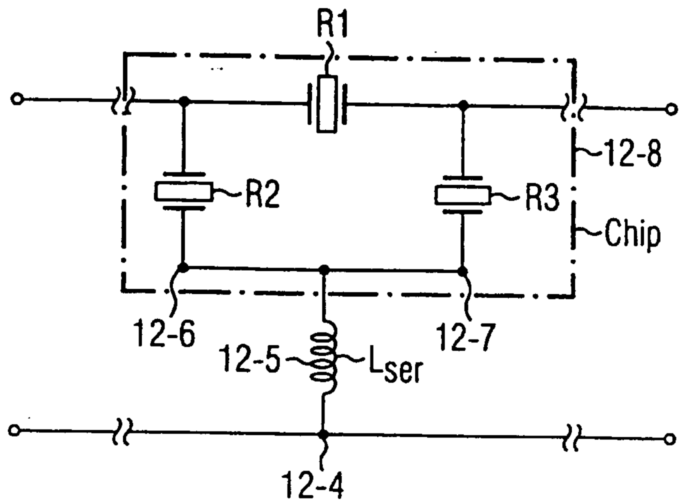


FIG 13

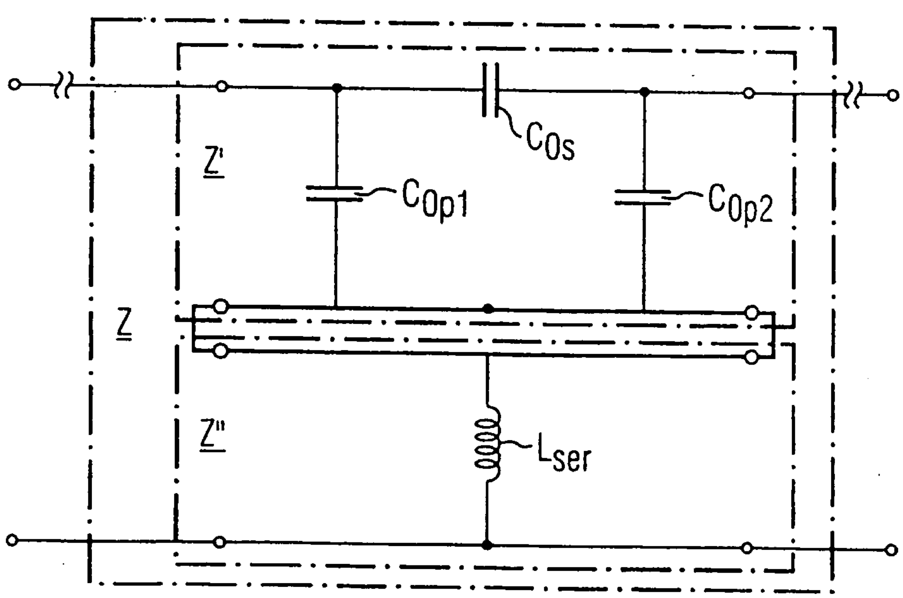


FIG 14

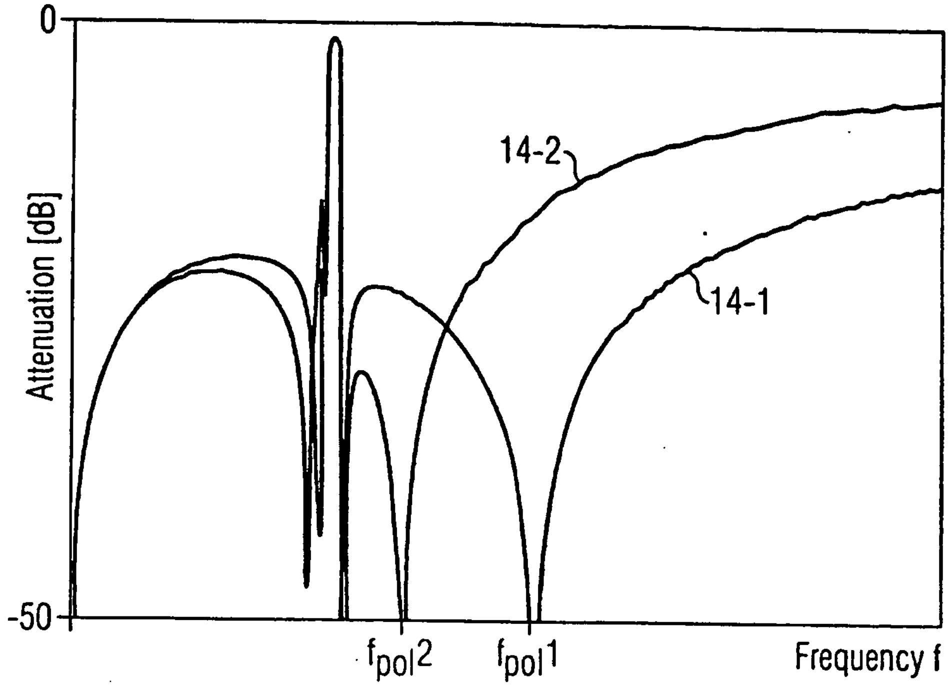

0
-50
Attenuation [dB]
14-2
14-1
$f_{pol}2$
$f_{pol}1$
Frequency f

FIG 15

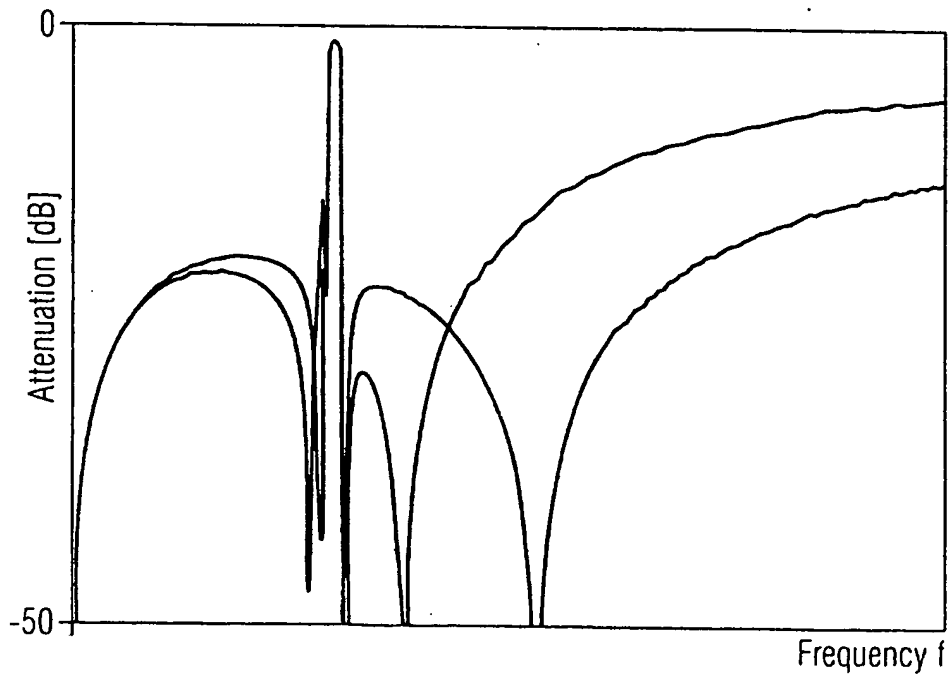

0
-50
Attenuation [dB]
Frequency f

FIG 16

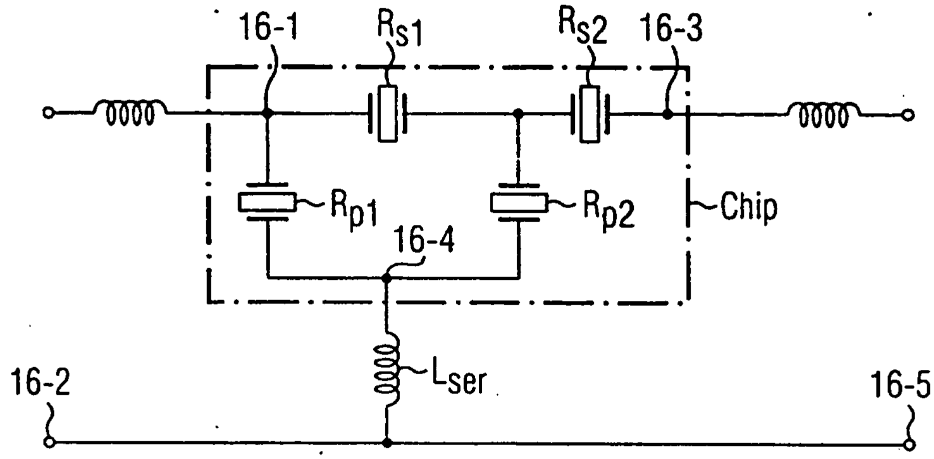

16-1
Rs1
Rs2
16-3
Rp1
Rp2
Chip
16-4
Lser
16-2
16-5

FIG 17

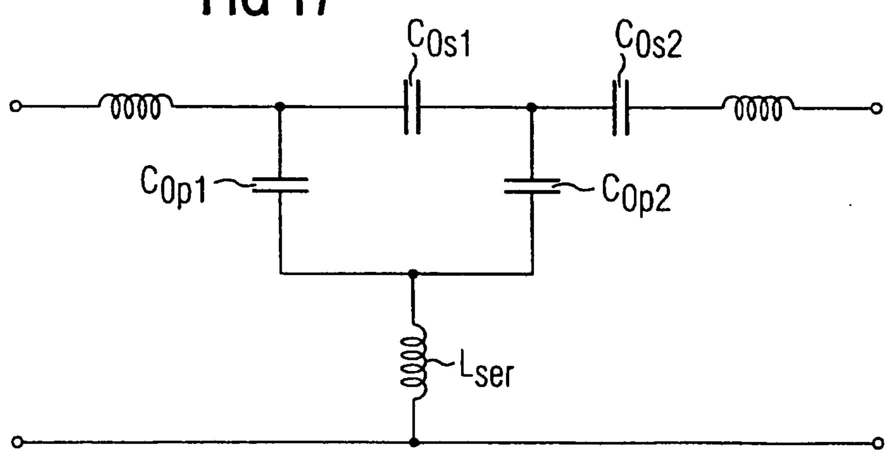

C0s1
C0s2
C0p1
C0p2
Lser

FIG 18

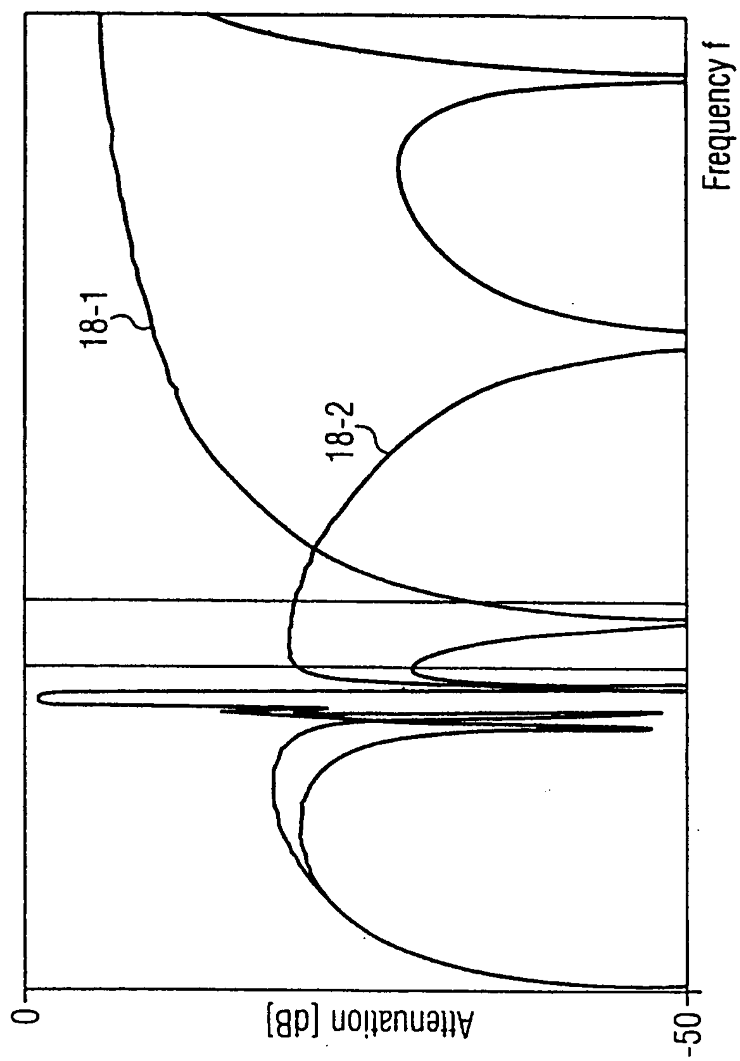
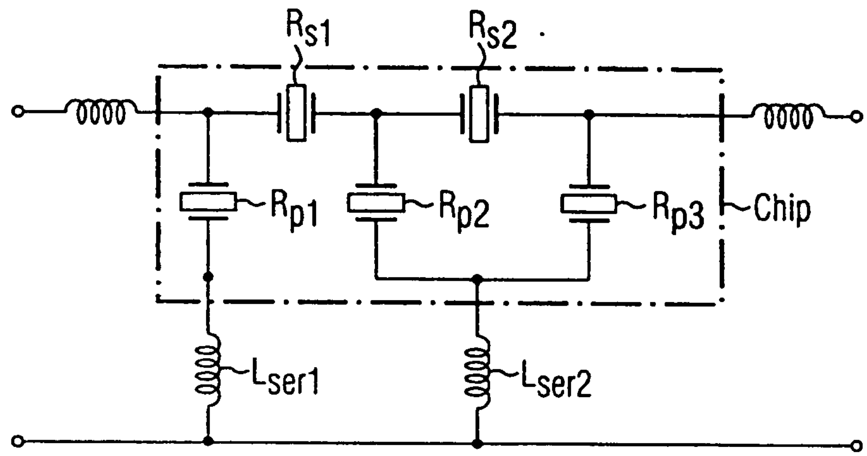
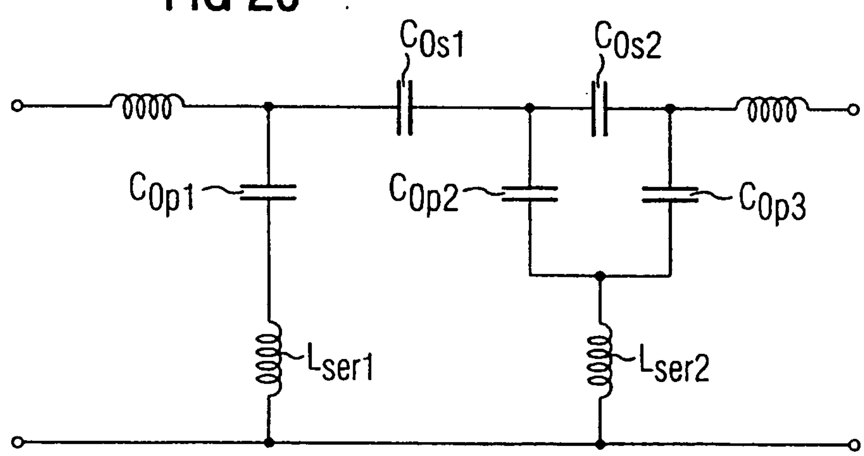


FIG 19



R_{s1}
R_{s2}
R_{p1}
R_{p2}
R_{p3}
Chip
L_{ser1}
L_{ser2}

FIG 20



C_{0s1}
C_{0s2}
C_{0p1}
C_{0p2}
C_{0p3}
L_{ser1}
L_{ser2}

FIG 21

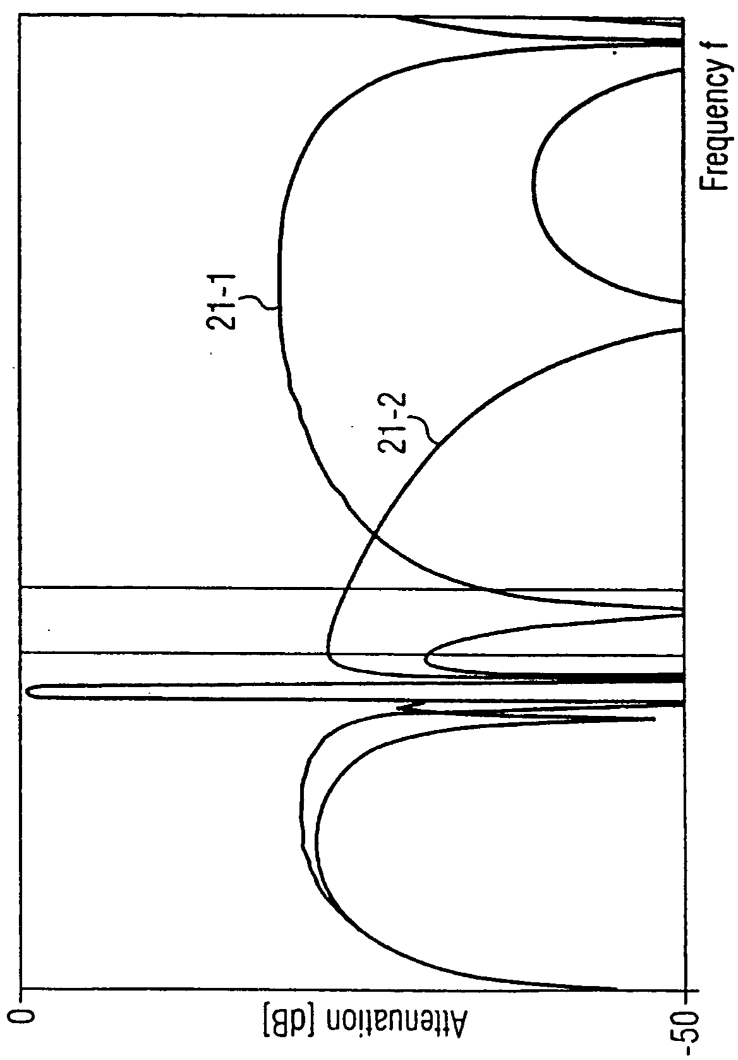


FIG 22

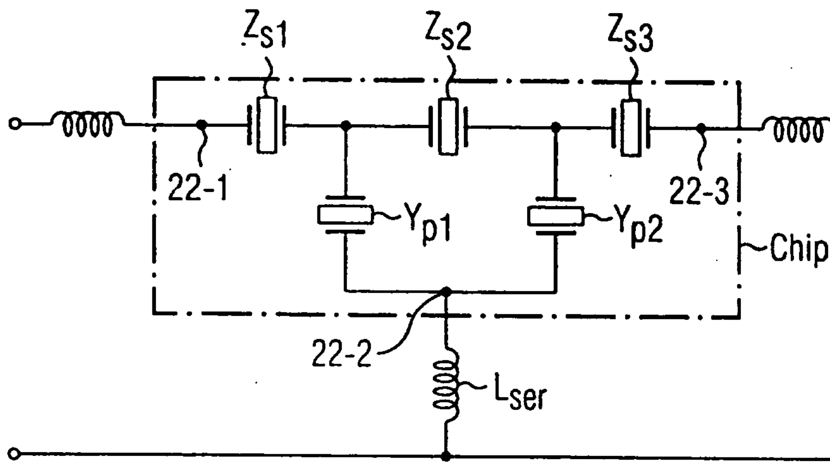

Zs1
Zs2
Zs3
22-1
22-3
Yp1
Yp2
Chip
22-2
Lser

FIG 23

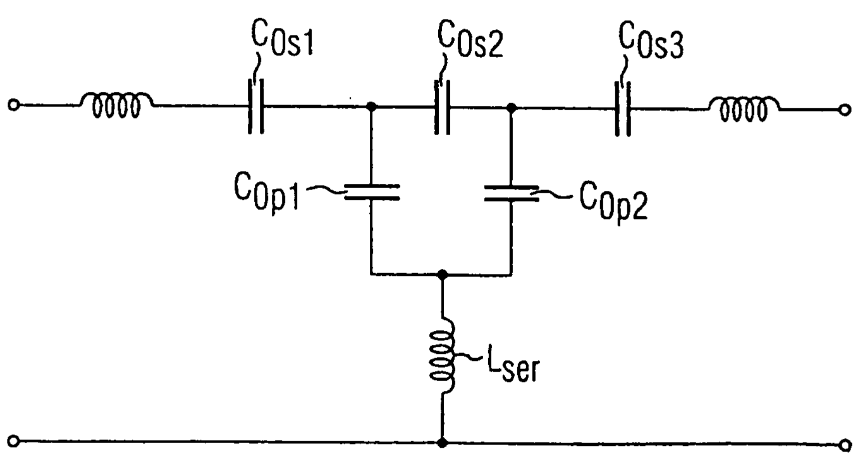

C0s1
C0s2
C0s3
C0p1
C0p2
Lser

FIG 24

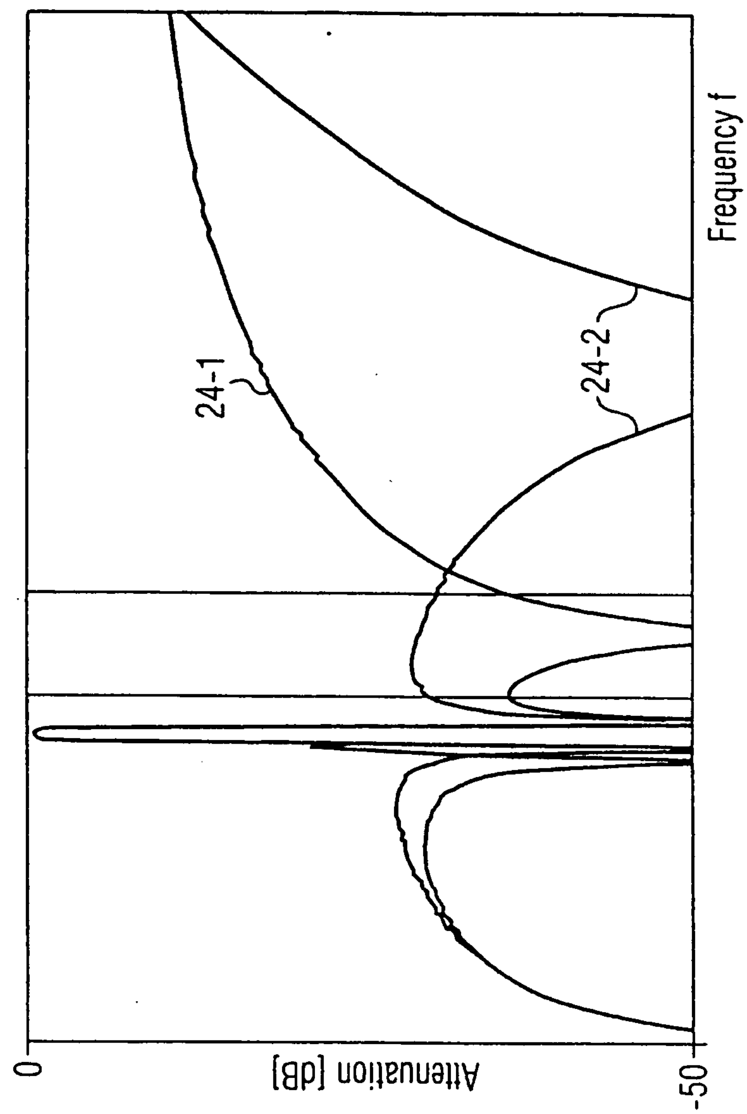
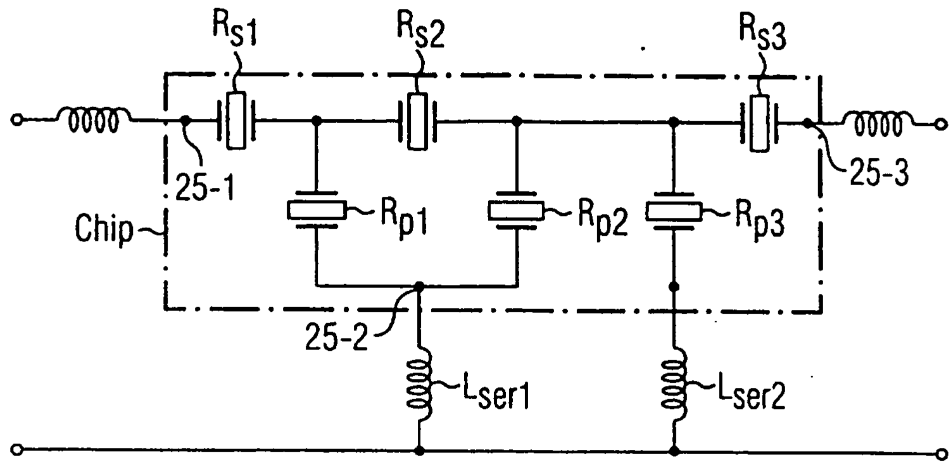
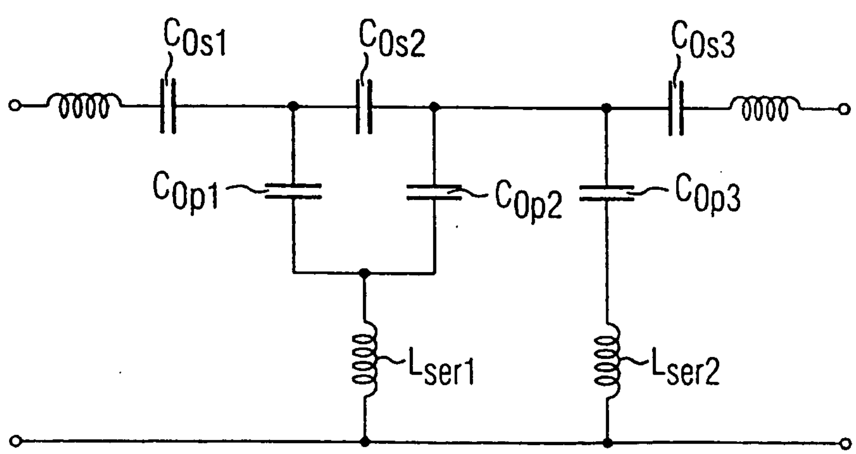


FIG 25



R_{s1}
R_{s2}
R_{s3}
25-1
25-3
Chip
R_{p1}
R_{p2}
R_{p3}
25-2
L_{ser1}
L_{ser2}

FIG 26



C_{0s1}
C_{0s2}
C_{0s3}
C_{0p1}
C_{0p2}
C_{0p3}
L_{ser1}
L_{ser2}

FIG 27

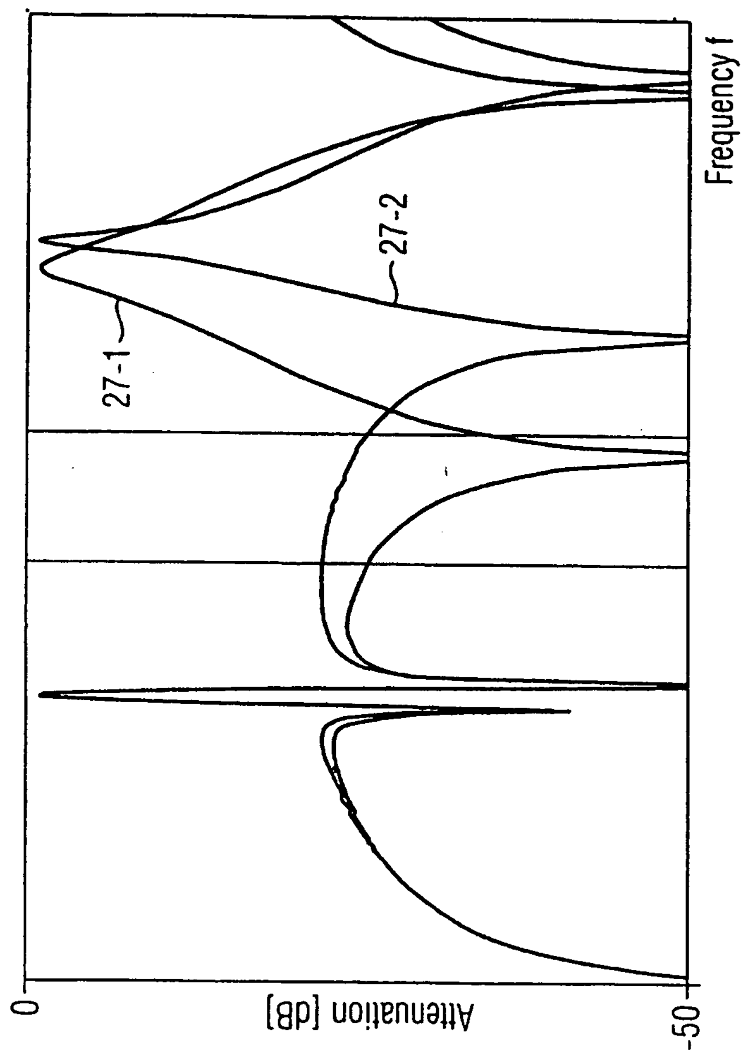
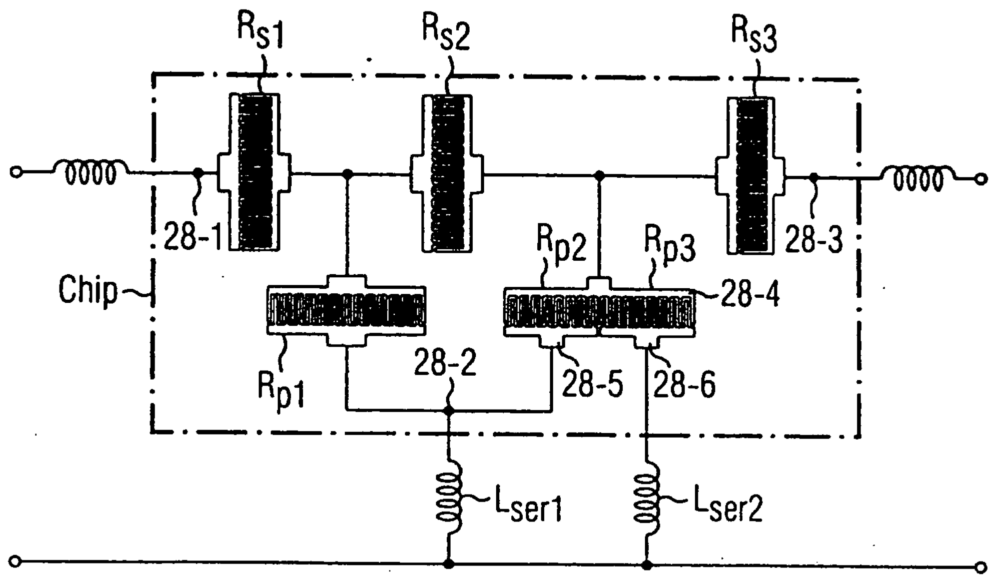
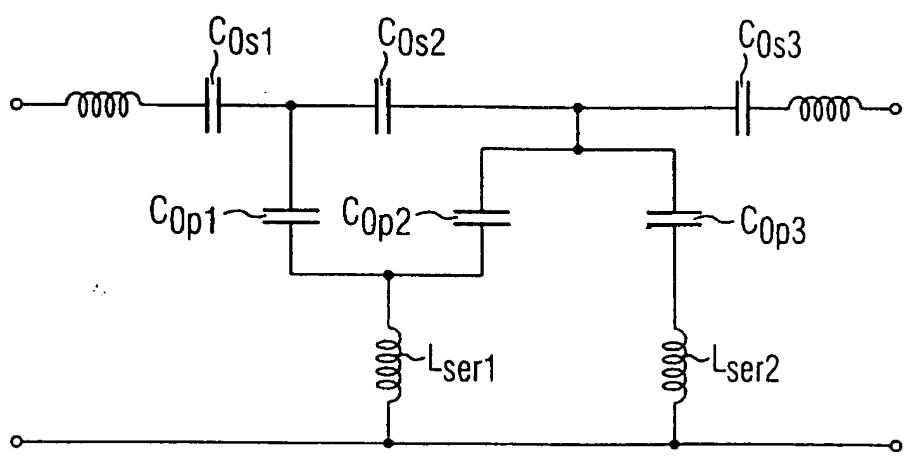


FIG 28



R_{s1}
R_{s2}
R_{s3}
28-1
28-3
Chip
R_{p2}
R_{p3}
28-4
R_{p1}
28-2
28-5
28-6
L_{ser1}
L_{ser2}

FIG 29



C_{0s1}
C_{0s2}
C_{0s3}
C_{0p1}
C_{0p2}
C_{0p3}
L_{ser1}
L_{ser2}

FIG 30

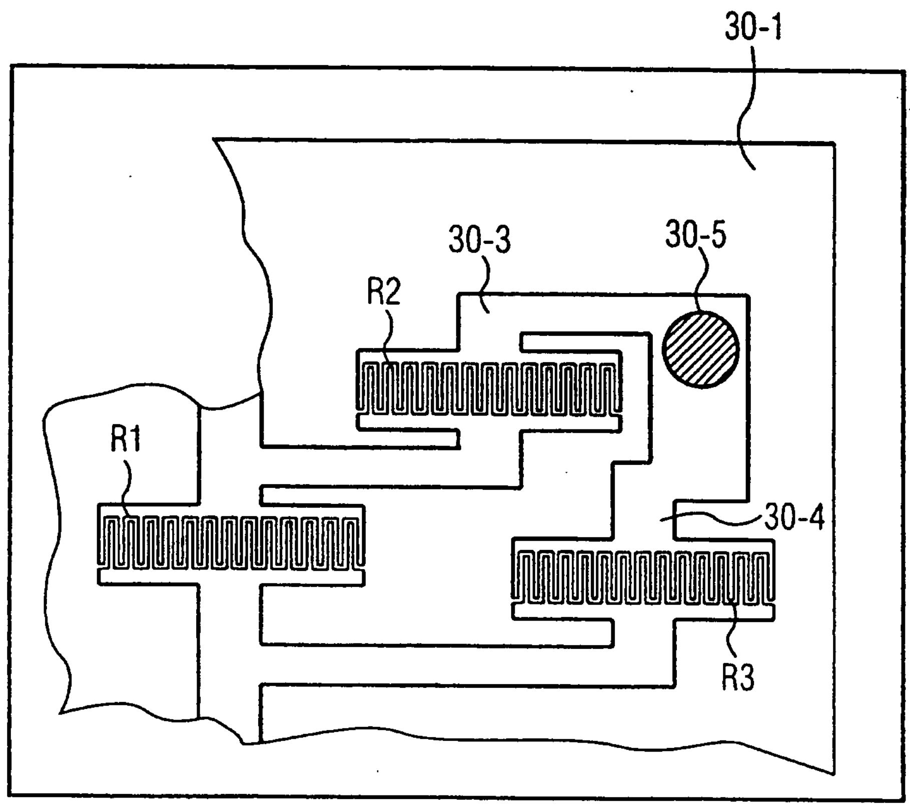
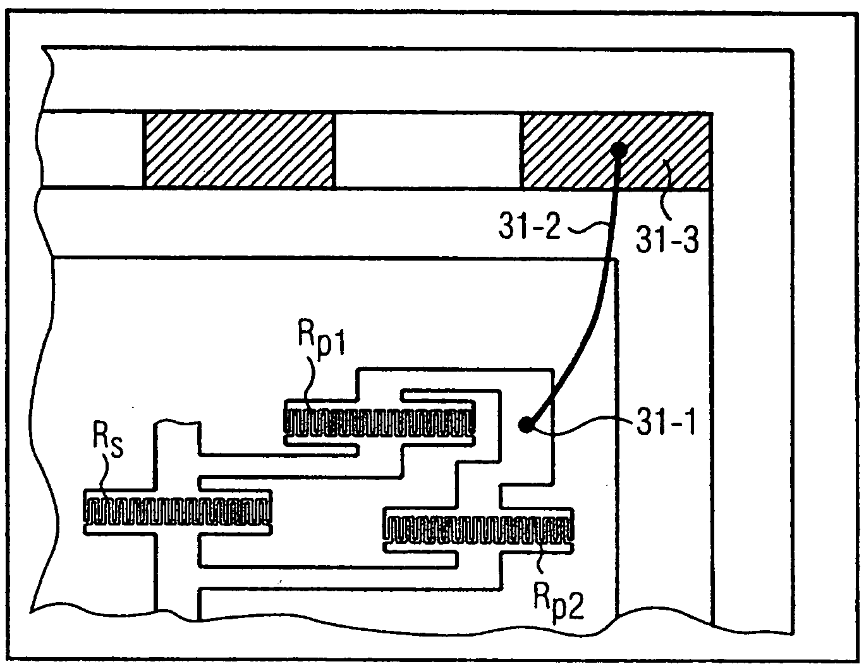
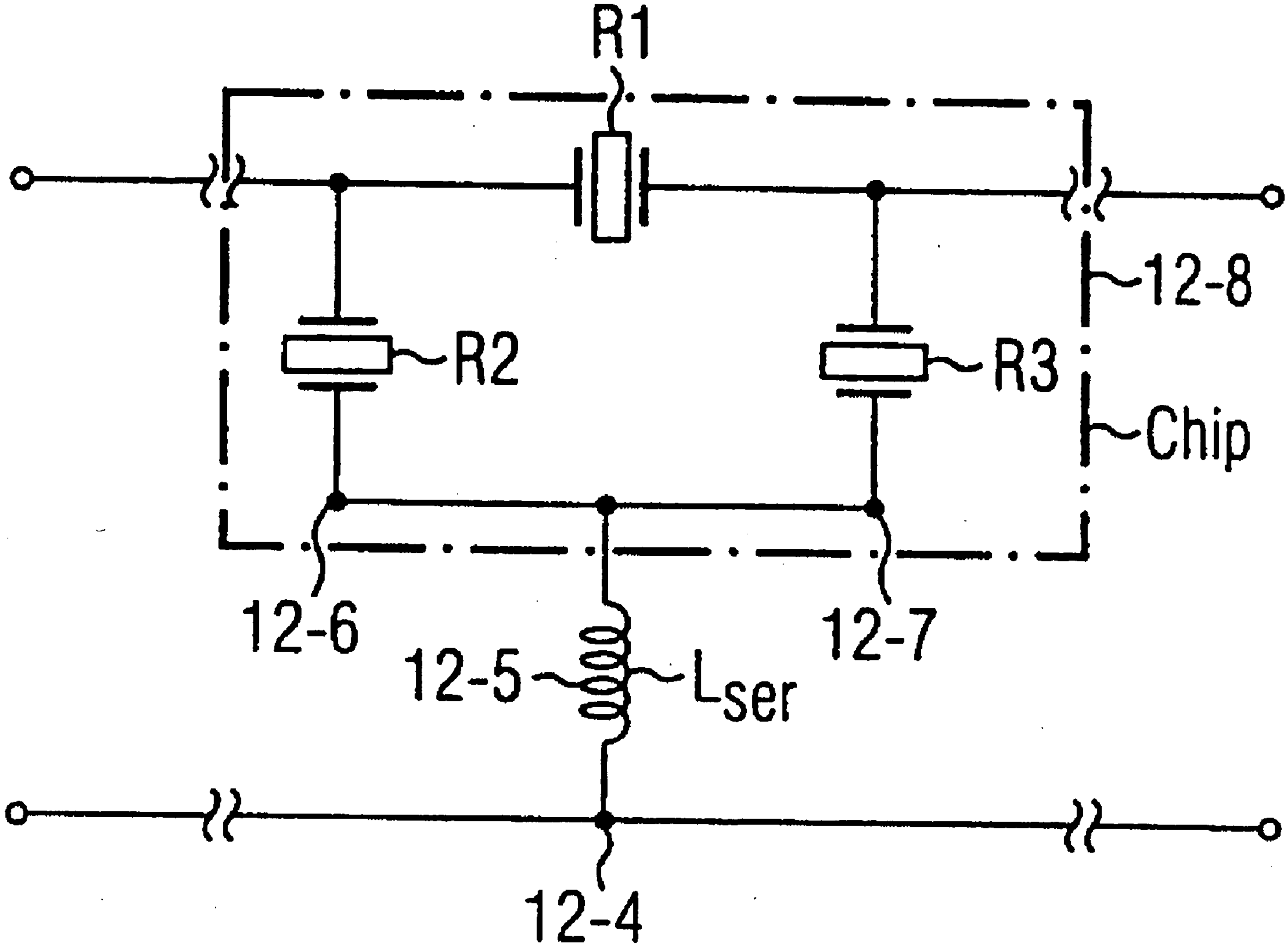


FIG 31




R1
12-8
R2
R3
Chip
12-6
12-7
12-5
Lser
12-4